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Overview of Concepts and Insights From Complex Systems

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Preface

The "Biosphere Sustainability Project" is an SSHRC-supported inquiry, more formally called "Citizen Engagement in Governance for Socio-Ecological Sustainability: Concepts and Case Studies". Its purpose is to [a] draw together concepts and insights, along with case study applications, from three rapidly developing areas of academic enquiry – complex open systems, sustainability of social-ecosystems, and civil society roles in governance -- and [b] determine (through consultations with examples) the potential application and usefulness of some of these concepts and insights for people associated with biosphere reserves in Ontario.

Biosphere reserves were chosen mainly because of the stringent criteria they must meet to receive this designation of recognition from UNESCO. The criteria include local organizational arrangements to be in place for developing collaborative capacities to address local and regional issues about the ecological, economic and ethical components of enhancing the sustainability for local communities and individual livelihoods. People associated with these local organizations are informed and committed to the ideals of sustainability and thus are in a good position to identify which perspectives, from among a range of concepts and examples from the academic literature, could be especially appropriate to the situations they are in and are striving to improve.

Introduction

This working paper provides an overview of complex systems thinking, and some applications of it, that can serve as a basis for initiating explorations of their use in the particular contexts of biosphere reserves in Ontario. The term “thinking” is used rather than “theory” because the variety of understanding about different kinds of systems has not yet yielded a widely accepted strong theory about them (e.g. Chu, Strand and Fjelland 2003). This review, based on varying approaches developed by different groups of scholars, is a revised and up-dated version of an earlier paper (Francis 2004).

The particular systems of interest here have been referred to as “self-organizing, holarchic and thermodynamically open”, or SOHOs (Kay and others 1999). Both ecosystems and social systems are examples. A number of approaches to complex systems thinking portray ecosystems and social systems in much the same way, but across a wide range of spatial and temporal scales. An overall “gestalt”, developed from general (open) systems theory originally associated with von Bertalanffy and colleagues, identifies the following systems’ attributes and processes:

Self-organization – morphogenesis through positive feedbacks dominate over negative feedbacks for extended periods of time

Emergent properties - not discernable in parts alone, but are a function of the entire system

Driven by exergy dissipation – non-equilibrium thermodynamics & dissipative structures including development of new units of organization

Hierarchical organization (systems-within-systems) – discontinuities in the distribution of structures across scales ("holons") -- leading to "holarchies" or "panarchies"

Developmental trajectories – co-evolutionary, structured by relatively small set of processes operating across scales

Strongly influenced by initial conditions of place (resources, constraints) – the systems have individual histories

Phase cycles – including collapses and starting over (no rigid "periodicities", but rather transformations from one phase into the next)

Multiple domains of stability (“attractors”) - systems can reconfigure (“flip”) sometimes rather suddenly (“bifurcations”) into other "basins of attraction"

Inherent indeterminancies within the systems - changes associated with contingencies and propensities

Large realms of uncertainty in knowledge (as well as indeterminacies) – can at best develop scenarios but not predictions

Therefore, the contexts for seeking sustainability are integrated social-ecosystems having these characteristics, complete with indeterminacies, uncertainties, and complete unknowns. There is no one best way to explore or think through systems phenomena of these kinds. One can enter the inquiry from just about any academic or professional field and from other kinds of lived experiences.

Approaches to Interpreting Complex Systems

Over the last 30 years or so, a number of different approaches have been taken through collaboration among scholars, or among some wider range of participatory groups to explore complexity and its implications. Considering only the more academic-based endeavours, some of which have incorporated "post-modern" critiques, there have been three main lead-ins to the explorations – search for “sense-making” processes that can lead to understanding and action within complex systems settings; formulation of detailed case studies of similar kinds of systems as they change over time in order to discern underlying patterns which may have causal importance; or elaboration and refinement of conceptual frameworks viewed as a pre-requisite for posing penetrating questions about systems of interest. Each entry point soon touches on the arena of the other two.

Moreover, these approaches have been explored by groups of natural scientists and mathematicians, and by groups of social scientists and historians, but not (so far as I know) by these two main groups working extensively together. This two-cultures divide remains deeply embedded. Some from their natural science base make generalized claims about the human world conforming to the universals they see associated with biophysical phenomena, but seldom go much beyond analogies or commentaries. Others from the social science base view complexity studies of scientists as evidence of a fundamental epistemological crisis within science itself, which threatens its legitimizing role for "modernism" and the underlying ideologies of liberal democracies and corporate capitalism. However, there appears now to be a growing interest in finding conceptual links between the two cultures, as noted further below.

Scale issues are pervasive. The different approaches to complex systems thinking adopt as their main foci, scales ranging from the global (planetary) through regional (continental or within countries) to the local scale over periods of time ranging from millennia and centuries through several decades to years or months. For use in the context of biosphere reserves, approaches based on extensive research and scholarship that can be used for "mid-scale" interpretation of systems phenomena were chosen. One set of approaches has a pre-dominantly natural science orientation, another has a social science orientation, and a third set, mainly dealing with "sense-making" processes, is applicable in both orientations. Table 1 identifies them. The groupings and their sequence do not imply a presumed order of intellectual significance, and like any taxonomy, they could readily be aggregated or sub-divided further for other purposes.

Table 1: Sources of Concepts and Insights from Complex Systems Thinking

[Names of the approaches are from their main proponents]

Primarily natural science oriented	*Primarily social science oriented*
"Panarchy and Resilience"	"Post-Fordism and the Market-State" &
"Ecosystem Approach" &	"Societal Autopoesis"
"Supply-side Sustainability"	"World-Systems Analysis"
"Self-Organized Criticality"	"Human Strategies in Complexity"

Applicable in Both

"Post-Normal Science"

"AMESH" (see text)

"Socio-cybernetics"

"Artificial Worlds"

Natural-Science Oriented Approaches

"Panarchy and Resilience"

These terms are associated with extensive studies by C.S. Holling and his associates that have extended over some 30 years. Major publications summarizing these endeavours in great detail include Holling (1978); Clark and Munn (1986); Gunderson, Holling and Light (1995); Gunderson and Holling (2002). The approach is based on detailed case studies of regional-scale ecosystems, changes associated with them over periods of several decades, and management responses associated with these changes. The ecosystems exhibit four phase cycles over a number of years or decades. The phases include periods of long-term relatively slow growth and development interspersed with shorter periods of "destruction" triggered by mainly by external events, followed then by renewal of growth. As diagrams, these phases have been depicted as figure 8s lying on their side (∞). The initial upswing phase from the lower left to the upper right (a forward loop from "exploitation" of new habitats to "conservation" of highly interconnected biomass) is followed at some point by a collapse phase ("release" or "creative destruction" – phrase borrowed from Schumpeter's economics) from the upper right back to the lower left. This is the back loop to a new beginning ("re-organization"). The re-organization may lead to a repeat of the cycle or to a new one if changed environmental conditions are encountered at the new exploitation stage.

The original "model" for this depiction is the fire-prone spruce-fir forests of New Brunswick that also experience spruce budworm outbreaks. Forest fires through accumulated dead wood result in a relatively rapid collapse phase. In other kinds of ecosystems, the back loop phases may be more drawn out. Freshwater lakes exhibit somewhat truncated phases between two equilibrium states of either a benthic or pelagic-dominated foodweb. These phase cycles operate at different scales set within loose hierarchical structures ("panarchies" = "holarchies") such that cycles at one scale can sometimes cause concurrent change at other scales. "Resilience" is related to the relative speed and extent of recovery during the destruction and renewal phases.

This interpretation of ecosystem dynamics forms the basis for extended critiques of resource management practices which focus on resource extraction rather than on maintaining the resilience of the ecosystems growing the resources. The paradox (or "pathology") of

resource management arises from contradictions between management actions which "produce" the resources and encourage local economic dependency on their continued provision, and the fact that the management actions also stress ecosystems to a point where, in extreme circumstances, some unanticipated event triggers their sudden collapse, along with the dependent local economy. An "adaptive management" strategy is advocated for these largely unknown situations. This strategy treats management as a kind of on-going experiment that should be monitored widely, especially in terms of changing ecosystem conditions, in order to give the signals for changing management approaches before they drive systems to collapse. The "panarchists" believe that the same situation applies to human systems which can be analyzed the same way either independently or as integrated social-ecosystems.

The results from a number of studies using these perspectives are summarized by Holling (1996; 2001), Peterson (2000), Carpenter and Gunderson (2001), Folke and others (2002; 2004), and Elmquist and others (2003). There has been some interest in applying the panarchy and resilience format to social systems. Examples include archaeological studies of ancient Mesopotamia and aboriginal settlements in the southwestern US (Redman and Kinzig 2003), and analyses of periods of change in the late Roman Empire and early 20th century Mexico (Weeks, Rodriguez and Blakeslie 2004 – who in passing noted an intellectual affinity of this approach with Oswald Spengler's early 20th century studies of historical cycles in, and the rise and decline of, civilizations).

The key to "adaptive management" is seen to lie in the resilience of social-ecosystems to relatively sudden and unanticipated changes that happen to or within them. This has generated interest in the resilience of complex adaptive systems generally (e.g. Adger 2000; Schoom 2005). A number of studies have investigated resilience in community-based resource management, especially situations where co-management evolved among different stakeholders and/or cultural groups, and situations having elements of shared common property resources (e.g. Berkes, Colding and Folke 2003).

A related debate is about the feasibility of adopting adaptive management strategies that are based on an experimental model which can be followed for a number of years (*vs* just "muddling through"). In many situations, the functional interdependence among the organizational overlays generate "tangled hierarchies" in administrative systems, "externalities" in socio-economic systems, and "environmental impacts" in ecosystems. Management

responses may have to be quite intensive and constant to deal with these kinds of situations (eg. Roe 2001; Roe and van Eeton 2002).

"The Ecosystem Approach"

This approach to complex systems shares the phase cycles interpretation of panarchy and resilience as well as the assumptions they also apply to human systems. It differs primarily in the emphasis that the ecosystem approach gives to the fundamental importance of non-equilibrium thermodynamics. The high quality solar energy ("exergy") is the driver of ecosystem development and is the essential pre-requisite for processing of materials and "information" (defined as the genetic code of organisms and biodiversity of ecosystems) into elaborate food webs. At the same time this helps dissipate the exergy. Exergy also drives ecosystems along some development path subject to constraints from initial conditions of place, and provides a crucial pre-requisite for the maintenance of their "integrity". If pushed beyond some thresholds, ecosystems can also reconfigure quite suddenly, in order to continue with their dissipation of exergy.

This interpretation of ecosystems addresses the generative side of evolution, i.e. the underlying processes which generate such rich biotic variety that natural selection processes can then occur (Schneider and Kay 1995). Through detailed studies of the energetics of foodwebs, and of their seasonal variation in Chesapeake Bay, Ulanowicz (1997) described the development of ecosystems in terms of their "ascendency" (*sic*) whereby at some point an internal balance is maintained between the continued development of dissipative structures (more elaborate foodwebs) and the conservation of adaptability ("ecosystem overhead") as a reserve for future adaptations to changing environmental conditions.

The non-equilibrium energy underpinnings of systems is deemed to be applicable to human systems as well. These too are dependent upon exergy as well as embodied energy in fossil fuels. The proliferation and complexification of human organizations in response to problem-solving needs or opportunities can be viewed as elaborations of dissipative structures that are crucially dependent on energy resources. Kaufman (2000) suggested that the proliferation of dissipative structures in response to exergy in physical systems, ecosystems, and human systems, can be viewed as another law of thermodynamics, one that applies for

open systems in contrast to the second law of thermodynamics about entropy in closed systems.

Allen and others (2003) elaborate on the thermodyamics of ecosystems while emphasizing the crucial importance of energy for the sustainability of human systems. They use as examples, historical and archaeological studies of collapsed societies that were unable to maintain their energy and other resource bases. (See also Tainter 1988; 2000). They also advocate "supply-side" ecosystem management which focuses on the restoration and maintenance of entire ecosystems in place of devoting attention only to the extraction of resources from them, a prevailing practice in resource management.

The "ecosystem approach" also places considerable importance on ontological and epistemological questions associated with how social-ecosystems, subsystems, and different biophysical and societal system types are perceived, defined, and applied across a range of different scales (e.g. Allen and Hoekstra 1992; Ahl and Allen 1996). Associated questions about the concept of "ecosystem health" and/or "ecosystem integrity" have attracted scholarly attention (e.g. Kay and others 1999; Kay and Regier 2000; Westra and others 2000; Ullsten and Rapport 2001; Wilcox and others 2004; Waltner-Toews 2004).

Applications of the "ecosystem approach" have made use of a heuristic protocol to guide applications of complex systems thinking, primarily for use in academic settings. It is used to guide questions and discussions about some particular situation of interest for a small group (or individual scholar) and it requires some re-iteration in order to help participants:

- Identify a particular system of primary interest – including relevant stakeholders, their issues of concern, preferred systems attributes or future vision;

- Develop systems descriptions – including the systems-within-systems (holarchies) and use of the main system types (perspectives) to analyze the system of primary interest;

- Identify self-organizational phenomena operating at each holon scale – noting the main factors which they seem to drive or which seem to be driving them, i.e. primarily abiotic, biotic, human/cultural, energetics;

- Consider current status and possible scenarios - desirable traits which might be strengthened and undesirable ones which might be reduced or de-activated;

- Prepare for adaptive management interventions - feedbacks to be addressed, governance arrangements to do this, monitoring.

This is a re-iterative agenda and not an easy one to work through or complete. Besides basic ontological and epistemological issues, other issues will arise including group interaction processes, especially as they relate to the social construction of knowledge and reflexivity, the lack of basic knowledge and information that any group will have about many elements of the wide scope of things to consider, difficulty in coming up with plausible scenarios and sorting out the governance, and deciding on what needs monitoring and how for adaptive management. It is these that lead to a lengthy process and the need for particular background studies. Waltner-Toews [and Kay] (2004) note similarities among this heuristic, the panarchy and resilience approach, and the Adaptive Methodology for Ecosystem Sustainability and Health (AMESH).

"Self-Organized Criticality"

The inherent dynamics of complex systems can result in their reaching critical states close to some thresholds of collapse where they nevertheless remain poised for long periods. Relatively small external disturbances may trigger responses ranging from slight perturbations to catastrophic change, with a power-law distribution for the magnitude of responses that occur, i.e. from many that are of small magnitude through to a few with larger magnitudes to an occasional major catastrophy. Major catastrophies do not necessarily imply unusual or special causes. The small external disturbances can trigger responses across the entire range. The "sandpile paradigm" (Bak 1996) has been used as a heuristic.

Examples often cited are earthquakes or extinction events, but the phenomena are deemed to occur in almost all self-organizing systems. Buchanan (2001:16) states that "…the ubiquity of the critical state may well be considered the first really solid discovery of complexity theory". It can be noted in passing that "panarchists" seem to dismiss this phenomenon (as others may do too) because of its close association with physical systems and the sandpile metaphor so often used to explain it (e.g. Gunderson and Holling 2002:62). Yet, the front loop of the ecosystemic phase cycles in the panarchy and resilience approach fits descriptions of self-

organized criticality, and the consequences of disturbances affecting the "conservation" phase are consistent with power-law formulations.

Brunk (2000; 2001) argues that the phenomena of self-organized criticality occur regularly throughout social systems. Many different societal arrangements evolve patterns of greater interdependencies to the point where internal or external disturbances are transmitted throughout the system as cascades of different magnitudes. The greater the number of outside disturbances, the less likely that self-organized criticality will generate large cascades. Brunk postulated that these phenomena constitute the underlying "engine of history" (2002a), and can explain societal collapse (2002b).

Devegas and Modelski (2003) combined "universal Darwinism" concepts for explanations of the general evolution of human systems through social learning, innovations and adaptations, with the idea of self-organized criticality poised within nested hierarchies of co-evolving social organizations. Disruptions from innovations or other sources cascade in power law fashion through the hierarchies. Most have little impact. Occasionally, however, some lead to quite drastic changes in economic, political and other social structures and in underlying cultural belief systems. Devegas and Modelski see prospects for elaborating "a deep theory of social order" from this perspective, one which might explain the evolution of the entire world system over the past 5,000 years, complete with the various phase cycles which unfold over periods ranging from decades to millennia.

Some Implications for Biosphere Reserves

Concepts and insights from these natural science oriented approaches to social-ecosystems should aid understanding of critical dynamics among the driving forces of changes in regional-scale landscapes and ecosystems of interest. A general protocol for applying the panarchy perspectives is being developed (e.g. Walker and others 2002; Taylor 2004). An application of this approach to dry-land range livestock economies in New South Wales, Australia (Abel 2000; Abel and Langston 2001) exemplifies the wide scope and extensive detail required for analyses of historical changes and responses to them that this approach can entail. Future scenarios are also used to guide thinking about current strategies and decisions. An example is the scenarios developed for assessing issues raised by exurban movements of people into the forests and inland lakes of the Northern Wisconsin Highlands Lake District

(Peterson and others 2003). Some of these issues would be familiar to people in Ontario biosphere reserves. Similar approaches for analyzing the Kristianstad wetlands complex in southern Sweden (designated as a biosphere reserve by UNESCO in June 2005) are described by Olsson, Folke and Hahn (2004).

Use of the panarchy and resilience approach also entails issues raised by the heuristic for the "ecosystem approach" as noted above, as well as awareness of other kinds of self-organized criticality. Along with basic ontological and epistemological questions, all of this will arise in the context of the social construction of knowledge and the need for reflexivity in the processes for doing this (see AMESH and socio-cybernetics, below). These kinds of considerations can lead to lengthy processes supplemented with special background studies to help them, or participatory engagement by informal local residents.

Social Science Oriented Approaches

"Post-Fordism and the Market-State"

The approach to analyzing this current situation is framed in the following context. First, it is set in a capitalist economy developed over many years to become both highly integrated globally as well as differentiated in the location and interactions of productive capacities, and these global arrangements exist in a world of almost 200 nation-states. Second, the relationships of relative power and collaboration between the institutions of the capitalist economy and those of nation-states have changed considerably within the industrialized (and post-industrial States) over the past 30 years or so. This coincided with a period of economic contraction associated with the most recent downswing of the Kondratieff, or K-cycles (see "world-systems analysis" below).

The narrative about this transformation usually begins with what was once (c1950s-1960s) the ideal of independent nation-states, each having a largely self-contained and balanced economic structure supported by strong social policies. They engaged in trade with other national economies through State-mediated rules about exchange rates, tariffs, limits on foreign ownership, and other measures all intended to protect the integrity of national

economies and polities. This ideal has been called a “Keynesian welfare national state with a Fordist mode of economic organization” (Jessop 2002). The reference is to mass production and consumption of goods and services (based on assembly-line technologies pioneered by Ford for automobiles in the early 20th century) and the adoption of Keynes’ economic theories whereby the State strived to maintain full employment and consumption levels (hence also production) through public spending during lags in business cycles. These arrangements were associated with the post-World War 2 economic expansion, characterized by relatively widespread material prosperity, some welfare state enhancement of wealth distribution, massive sub-urbanization supported by enlarged highway networks and other infrastructure, and an increasing dependency on automobiles.

This ideal became increasingly unworkable by the 1970s, especially with the on-going K-cycle downswing in the global economy. Most industrialized countries then entered a period of high unemployment, low growth with high inflation (“stagflation”) and increased public debt. This led to the corporate capitalist, “neo-liberal” economic (and “neo-conservative” political) backlash to remove or undermine the policies and regulations that nation-states had in place. The easing of State controls of the private sector facilitated the rapid expansion of global capitalism, with innovative and specialized production for increasingly diversified markets (*vs* mass sameness), and the strengthened influence of trans-national corporations. Some national government powers were redistributed “upwards” to international institutions that fostered global capitalism, “downward” to more local levels of government under the rubric of subsidiarity or debt reduction, or just abandoned as no longer necessary (“de-regulation”).

States also took various roles to promote the interests of global capitalism by reducing taxes, cutting welfare entitlements, promoting “flexible workforces” (“workfare”), restricting union powers to protect wages and working conditions, privatizing public utilities and services, and promoting “competitiveness” and “productivity” as defined by the private sector. Governments also competed with one another to attract knowledge-intensive, innovation-oriented “new economy” investments in urban regions. These oases of growth helped exacerbate patterns of uneven development and widened inequalities between rich and poor (e.g. Jessop 2002). As the social and environmental costs and contradictions of this neo-liberal alternative become increasingly apparent, so do attempts to find ways to re-balance capitalism with broader societal goals and curb its more destructive tendencies. There are extensive debates about this (e.g. Broad 2004).

From a systems perspective, these issues have been viewed as recurring phenomena of the embedding and disembedding of capitalism in other dimensions of society, ones that provide essential support for capitalism while also being exploited by capitalism unless it can be reigned in. Different perspectives have been taken to describe or explain this (e.g. Jessop 2001; Schneider n.d.). “Regulation theory” interprets it as the politics of dialectical interactions among economic and other societal institutions necessary to resolve inherent contradictions arising from functional interdependencies among them. These give rise to new regulatory frameworks or “spatial-temporal fixes” that are quite location-specific, often set in the context of some urban region while ignoring old jurisdictional boundaries, rather than extending to an entire nation-state. These new arrangements are inherently temporary (lasting maybe a few decades at most) because the underlying contradictions remain (e.g. Lipietz and Benko 1998; Broomhill 2004).

The neo-liberal concept of a “market economy” that can function largely on its own as if detached from other social formations has also been viewed as an example of “societal autopoesis” discussed at length by the German social theorist Niklas Luhmann (Jessop 2001). Luhmann’s theory draws upon sociocybernetics as well as the biological concept of “autopoesis” for living systems. Organisms have a fixed genetic code governing the growth and reproduction of their molecular and cellular components but at the same time they must remain “structurally coupled” with their environment to acquire essential nutrients and other pre-requisites for living. “Autopoesis” thus refers to some entity which continually reproduces itself while remaining organizationally closed but structurally open for limited contact with an outside world.

This construct has been adopted by Luhmann to define “society” as nothing more than closed self-referential communication networks which are structurally open to their environments, which in this case are other communication networks (see especially Luhmann 1995). Each such network is self-reproducing and can grow with access to resources. It filters information from its environment through strict binary codes to convey meaning for itself on its own terms. From this perspective, society is only an aggregation of such networks rather than some emergent larger entity (Bechmann and Stehr 2002; Viskovatoff 1999). A somewhat modified version by Dempster (2001) interprets social organization as “sympoetic” which suggests that organizational closure is not complete but remains somewhat “ajar” and this in turn allows for some cultural evolution.

Other interpretations of these changes, based on long-established theorizing in traditions ranging from liberalism to Marxism, are not pursued here. This focus on recent transformations in market economies can also be viewed as a subset of world-systems analysis, although the relevant scholarship seems to have been developed independently. The ambivalence about including K-cycle interpretations is an example. Conversely, it has given rise to considerable scholarship on the implications for "governance".

"World-Systems Analysis"

This approach to complex systems is probably the most heroic of them all. At its grandest extent it sketches the "rise and demise" of entire societies from pre-Neolithic times some 12,000 years ago to the present era (Chase-Dunn and Hall 1997), or globally over the past five millenia (Frank and Gill 1996). More attention has been given to the past 500 years or so, the period which has seen the rise (and more recent curiosity about the demise) of global capitalism in a world of nation-states (e.g. Wallerstein 1999; 2005; Chase-Dunn 2001).

From the world-systems perspective, the material base for societal change comes primarily from the "unceasing accumulation of wealth" which is the driving force of capitalism and the purpose of existence for corporations, combined with struggles for domination over the state apparatus for control over territory, resources and people within nation-states. Rivalries and conflicts abound, but the wealthy need the powerful to protect their wealth and the conditions under which they can continue to accumulate it, and the powerful need the wealthy in order to maintain their territorial control. As this has unfolded repeatedly over many decades it has created a functional and spatial differentiation of the world society into core countries having the most advanced technologies and organizational know-how for different economic sectors. In contrast, peripheral countries supply little more than resources and cheap labour, and the semi-peripherals in between usually have an urban sector more closely linked to core economies and rural areas that are peripheral (e.g. Chase-Dunn and Grimes 1995). The same structural relationships are replicated within countries as well.

Phase cycles or transitions of particular interest in the world-systems perspective are all multi-decadal. They include economic phases of expansion, diffusion and contraction over periods in the order of 50-60 years. The phenomena are usually referred to as "Kondratieff, or

K-cycles" which are associated with access by core countries to major new resources and/or technological innovations which can undermine and replace economies based on older technologies. Over much longer periods, the "systemic cycles of wealth accumulation" in the core economies shift their geographic location when overseas investments and/or growing financial speculation provided by institutions in the old core region generate better rates of return elsewhere. The eventual result is that a new regional economy develops from such investments while the old region coasts along with slowly aging infrastructures and unresponsive institutions (combined often with assumptions about cultural superiority). Over a century or more, the new regional centres for wealth accumulation regularly outcompete the old, and the inter-regional disputes become increasingly politicized (Arrighi 1995).

There are also phase cycles associated with the political rise and demise of hegemonic powers that preside over the world order. Economic and political conflicts that develop between a prevailing hegemon and its allies from a challenger group lead eventually to drawn out international wars. When a challenger succeeds by "winning" the wars or just surviving them in better economic condition than other combatants, it then can set or enforce the international groundrules to direct some new world order for security and trade in which the winners are the primary beneficiaries. For a time this is widely accepted in the aftermath of major wars. Some decades later, this world order becomes increasingly less relevant for dealing with new problems and challenges to it. The hegemonic arrangements then begin to lose their legitimacy and new coalitions form to challenge the hegemon or some other contenders on the world scene. The four phases of a hegemonic cycle, given the history of several of these over the last several centuries, also take a century or more to unfold. In each case, the defining wars (e.g. Napoleonic wars; World Wars 1&2) were the most destructive ever known up to that time (Modelski 1987; 1996; Bornschier and Chase-Dunn 1999).

Besides these grand cyclic phases, the world-system has exhibited major trends or "trajectories" of development. These include extensive population growth; a material well-being for many people but along with growing inequalities in its distribution; an increase in the number of nation-states; a large increase in the number of transnational corporations and international "civil society" non-governmental organizations; a massive increase in economic production combined with increasing capital intensity of production (labour displacement); intrusion of commodified goods and services into all spheres of modern life; and massive environmental degradation in many forms.

There is some question about whether or not the major phase cycles of old can still play themselves out under conditions of approaching global ecological or other limits. If not, then some entirely new "system flip" may be in the offing (Wallerstein 1998; Hopkins and Wallerstein 1998; Arrighi and Silver 1999; Boswell and Chase-Dunn 2000). Modelski (2003) suggests one possibility is entry into another long era (millennium) similar to two previous "dark ages" characterized by cessation of socio-economic growth, reduced concentrations of people in large settlements, social disorder, relaxation of pressures on the environment, and diffusions (redistribution) of wealth and power. This era would be part of the largest of all phase cycles in an evolutionary world system.

These world-system processes do not unfold without considerable protest and resistance. "Anti-systemic" movements organized around different cultural ideals have always tried to modify or transform dominant political-economic trends. From the mid-19th century, these were most often movements to gain access to State institutions (by democratic processes or otherwise) in order to command changes in the name of greater democracy, social equality, or national liberation (anti-colonialism). While these were quite successful at gaining access to, or control of State structures by the first decades of the 20th century through to the 1950s, disappointments with what was accomplished by achieving command positions led to growing disenchantment with the State. From about 1968 on, anti-systemic movements took the form of general protests, rejection of official institutional authorities, creation of new forms of voluntary communities, and strong demands for recognition of social entitlements, or of previously submerged personal identities and life styles (e.g. Arrighi, Hopkins and Wallerstein 1989).

This has been exemplified by recent contrasts made between global meetings of political and economic elites under heavy miltary and police protection, and the more carefree and celebratory gatherings of the World Social Forum in Brazil and elsewhere (Wallerstein 2005). The latter reflect the potential of world-wide networks forging horizontal links through new information and communication systems. The political implications and consequences are yet to be known.

This approach has been embarked upon through an ambitious inter-university group in Europe to develop the "philosophical foundations for a theory of evolutionary systems". It selects a few key "onto-epistemic problems" starting first with phenomena such as self-organization, emergence, and the role of "information" in systemic processes. The resulting discourse adopts a theme of "structuration by dialectical processes" to interpret self-organization and emergent properties in social systems. This approach draws upon the "structuration theory" of Anthony Giddens to interpret social structures as emergent phenomena which are constantly created and re-created by people following rule systems to guide their behaviours. In this view, structures are not some kind of pre-existing social architecture that exist independently of peoples' lives. If rules change, so will the structures created by new rules. This idea is coupled with that of "dialectics" in which the merger of opposites or resolution of contradictions (however defined) leads to a synthesis which in turn has its own opposite to merge into another synthesis (and so on). This kind of progression can be viewed either as an ontological description of social change or as a mode of reasoning about change (epistemology), or possibly both (Fuchs 2000a; 2000b; Klauninger 2002).

Comparable interpretations have been given by Hofkircher (1998). Rosser (2000) examined three principles of dialectical analysis in terms of how they appear to be incorporated (using different language) into nonlinear dynamics models of complex systems phenomena. A somewhat similar ambitious project, the "Principia Cybernetica Project", to address foundations and methodologies for an evolutionary world view, is described by Heylighen (c2000).

The focus on emergent social structures and change as a question of rule systems, and on the formulation of opposites to whatever it is thought desirable to change, provide worthwhile insights for understanding governance issues. Desirable changes to enhance sustainability should focus on rules (laws, regulations, tax subsidies, power relations) which have become barriers or constraints.

Some Implications for Biosphere Reserves

World-systems perspectives along with the rise of the "market-State" and continuous discussions about "globalization" note the deep historical context and driving forces which underlie much of what happens at smaller scales throughout the world. Environmental and

ecological considerations have generally not been included until recent years. Some scholars point out early works where environmental contexts were discussed in different terminology (e.g. Moore 2003a). Links between environmental history and world-systems are also being explored (e.g. Crumley 2003a; 2003b; Moore 2003b). Growing contemporary concerns about possible impacts of climate change may contribute to this (e.g. Chase-Dunn, Alvarez, and Pasciuti 2002).

These grandiose perspectives provide for a "snapshot-in-time" of the historical forces which are unfolding and set the background for any more localized dialogues about sustainability. At the present time then, in the world polity, the US as the most recent hegemon has been in slow decline for the past 30 years or so to the point that it now relies on brute military force to rule in place of exercising a trusted leadership with broad-based legitimacy and acceptance (e.g. Wallerstein 2003). Delegitimation processes are well underway for most of the post-world war international organizations such as the UN system or NATO. The major centres for systemic cycles of wealth accumulation are shifting from the US (and Europe) to Asia which is fast becoming a significant economic competitor in the global economy. The past 30 years or so coincided with a "downswing" in the K- cycle, but arguably a new upswing is underway which is driven by information technologies, nano-technologies, robotics, and biotechnologies, many of which are thriving in Asia as much as they are in the North America and Europe.

Every place in the world is set within a global context with these kinds of issues. Interpretations of them could vary widely, especially since the world-systems perspectives are not supportive of prevailing ideological justifications for economic or military responses to "globalization". Concepts such as self-organized criticality and dialectical processes may help. But these phenomena are not merely passive backdrops for the real world of local and immediate concerns. Systemic interconnections point to constraints, perhaps serious ones, on what can be achieved or maintained locally in biosphere reserves through citizen community engagement and community-based networks.

However, appropriate elaboration of this would require further study closer to the scales at which biosphere reserves operate. A number of studies deal with issues of neo-liberalism and market-State initiatives in Canada, Ontario and the Great Lakes region. These should be reviewed and drawn together for possible application to some or all of the Ontario biosphere reserves. Incorporation of these perspectives into the kinds of analyses proposed by the

panarchy and resilience approach to complex systems would add much needed strengthening of societal insights than have been undertaken so far. But it would also complicate the process and could test the patience of natural scientists who usually dominate these analyses.

Approaches Applicable in Both "Cultures"

"Post-Normal Science"

This term was coined by Jerry Ravetz and Silvio Funtowicz to refer to situations where uncertainty is high, the need for decisions is urgent, the consequences or stakes are high, but there is little usable science to rely upon. Much of the sustainability debate is in this realm. These situations require extended peer reviews to draw upon a wider range of knowledge and experience to arrive at some judgement (Funtowicz and Ravetz 1993; 2003; Ravetz 1999; 2004).

In situations where "experts" are hired by government, corporations, or other organizations to argue a particular case, other experts and knowledgable citizens are needed to expose the underlying assumptions, accuracy, (in)completeness, and ethical implications of what is being asserted. To the extent that greater accountability and transparency is brought to the decision-making process in this manner, social trust in it may also be enhanced. This interpretation of complex systems helps support collaborative approaches of various kinds on both epistemological and ethical grounds.

"Adaptive Methodology for Ecosystem Sustainability and Health (AMESH").

The AMESH approach draws upon complex systems thinking, post-normal science, participatory action research, soft systems methodologies, and adaptive environmental assessment and management. This assures multiple perspectives and methodological pluralism for addressing sustainability in a community engagement process. Inclusion of people most affected by local problems can bring good insights into what could be done. The success reported by AMESH carried out in developing countries was associated with inclusion of people who would normally be excluded from decision making because of local ethnic, gender, or class

discrimination (Tamsyn and others 1999; VanLeeuwen and others 1999; Waltner-Toews 2003; Waltner-Toews and others 2003).

The AMESH approach reinforces the importance of collaborative approaches, especially for cross-cultural situations. It resonates with the experience reported from studies on the resilience of social-ecosystems, and especially on community-based resource co-management projects with aboriginal peoples (e.g. Armitage 2005; Berkes 2005).

"Sociocybernetics" (Second Order Cybernetics)

First order cybernetics refers to the cognitive interactions of observers who are observing systems outside of themselves, and through the interaction of observer with the observed, develop their perceptions and understandings accordingly. Second order, or sociocybernetics refers to the same processes but for situations in which the observers are inside the systems they are observing, and realize this (Geyer and van der Zouwen 1991; Geyer 1994). Thus their interactions with the systems could modify the systems themselves. Awareness of this is necessary to enhance reflective thinking ("reflexivity") about the "social constructivism" of knowledge that is inherent in "observing observed systems" (Connell 2002/2003; Manuel-Navarrete 2003). Consciousness of this can result in "double-looped learning" if management of the system is the object of the exercise, i.e. both the goals or purpose of management as well as the means to achieve them are open to critique and change. In other situations, this "deep reflexivity" can lead to some transformation of consciousness in the observers.

There can be a regress involved in trying to understand the phenomena of observers observing themselves and others observing the system they all are in. A "radical social constructivism" for interpreting knowledge can result, to the point of rejecting even the possibility of an ontology for the systems of interest. These will be among issues that a process based on reflexivity would have to address.

Given the phenomena of "observing systems" along with the social construction of knowledge and the need for reflexivity, Midgely (2003) argues that the best approach for dealing with complexity is to adopt methodologies for interventions that make "sustainable improvements" in social conditions. Value judgements need to become explicit for setting

boundaries to whatever is being addressed, and adopting theoretical and methodological pluralism to guide decisions and actions for making the improvements. Midgely's rationale seems both appropriate and supportive of collaborative processes and community engagement.

"Artificial Worlds"

It is argued that computer simulations are a new way to do science in the information age (e.g. Casti 1995; Morris 1999). There is a vast range of explorations underway through networks such as the Sante Fe Institute (www.santafe.edu), (e.g. Waldrop 1992), the New England Complex Systems Institute (www.necsi.org), and the European Complex Systems Network of Excellence (www.complexityscience.org) (e.g. Casti and Dum 2002). They each use computer simulations to identify rules that govern "information" processing within complex adaptive systems and the resulting emergent functional or behavioural patterns that are associated with different rules. One focus for exploration is algorithmic rules (logic) which lead to "deterministic chaos" in biophysical systems. Another, for human systems, is how artificial "agents" make decisions based on rules, but they can change the rules when new information becomes available so that the emergent behaviour is continually adapting to changing circumstances. The potential of this approach is also being explored in the context of organization behaviours.

There is a vast literature on this subject to the point that computer simulations and "complexity studies" are sometimes presented as if they were synonymous. Much of the literature is technical, and concerns problems and methods for programming, and discussion of fine points of numerous simulation runs. The relationship between screen patterns and the world raises epistemological issues, including that of psychological projection and reification from the one to the other. Simulations that can be correlated with extensive empirical data hold the most promise (e.g. Dearing 2003). One example from archaeological studies in the southwestern US is described by Kohlr, Gumerman and Reynolds (2005). For consultation processes which use simulation models, the debates about artificial (virtual) worlds should be considered as part of the reflexivity of the process. Otherwise, as a kind of "post-normal science", the same critiques apply about their use and possible misuse.

Some Implications for Biosphere Reserves

These approachs can be seen primarily as "sense-making" ones that can help groups sort out a shared understanding of situations they are confronting. Ambiguities and uncertainties abound. Computer simulations are mainly for research purposes, but certain kinds of consultations such as "Participatory Integrated Assessments" (for issues such as response to climate change, or policy changes for certain social or economic sectors) use models of various kinds to help visualize and clarify issues and stimulate thoughtful discussion. Examples include models of climate change, geographic information systems to illustrate landscape features, and models for sustainability of a given sector or region. The models themselves can become the focus of debate and criticism, rather than what they try to depict.

Biosphere reserves operate through volunteer collaborative networks, and are sensitive to issues of building and maintaining trust and commitment among members of the networks. Most of the time, the focus is on rather immediate, pragmatic objectives that members of the networks have agreed upon (as evidenced in their continued direct participation). However, as the groups delve into new areas or more difficult issues, elements of these sense-making approaches may become relevant. This is a question for exploration with people in the biosphere reserves.

References Cited

Abel, Nick. 2000. *Sustainable Use of Rangelands in the 21st Century: On the road to a better future for the Western Division of NSW*. Canberra: CSIRO.

Abel, Nick, and Art Langston. 2001. *Evolution of a Social-ecological System: Adaptation and Resilience in the New South Wales Rangelands 1850 to 2020*. (Draft)

Adger, W. Neil. 2000. Social and ecological resilience: are they related? *Progress in Human Geography*, 24(3):347-364.

Allen, Timothy F.H., and Thomas W. Hoekstra. 1992. *Toward a Unified Ecology*. New York: Columbia University Press.

Allen, T.F.H., Joseph A. Tainter and Thomas W. Hoekstra. 2003. *Supply-Side Sustainability*. New York: Columbia University Press.

Armitage, Derek. 2005. *Adaptive Capacity, Social Capital and Co-Management*. Paper for the Adaptive Co-Management Symposium. Wilfrid Laurier University, February 2005.

Arrighi, Giovanni, Terence K. Hopkins, and Immanuel Wallerstein. 1989. *Antisystemic Movements.* London: Verso.

Arrighi, Giovanni. 1995. *The Long Twentieth Century: Money, Power, and the Origin of Our Times*. London: Verso.

Arrighi, Giovanni, and Beverly J. Silver. 1999. *Chaos and Governance in the Modern World System*. Minneapolis: University of Minnesota Press.

Bak, Per. 1996. *How Nature Works: The Science of Self-Organizing Criticality*. New York: Springer-Verlag.

Bechmann, Gotthard, and Nico Stehr. 2002. *The Legacy of Niklas Luhmann*. Society, 39: 67-75. (January-February 2002).

Berkes, Fikret, John Colding, and Carl Folke (Eds.) 2003. *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change*. Cambridge University Press.

Berkes, Fikret. 2005. *Adaptive Co-Management and Complexity: Exploring the Many Faces of Co-Management.* Paper for the Adaptive Co-Management Symposium, Wilfrid Laurier University, February 2005.

Bornschier, Walter and Christopher Chase-Dunn (eds.) 1999. *The Future of Global Conflict*. London: Sage Publishers.

Boswell, Terry and Christopher Chase-Dunn. 2000. *The Spiral of Capitalism and Socialism*: *Toward Global Democracy.* London: Lynne Rienner.

Broad, Robin. 2002. The Washington Consensus Meets the Global Backlash: Shifting Debates and Policies. *Globalizations*, 1(2):129-154.

Broomhill, Ray. 2004? Neoliberal Globalism and the Local State: A Regulation Approach. *Journal of Australian Political Economy*, no. 48: 115-140.

Brunk, Gregory G. 2000. Understanding Self-Organized Criticality as a Statistical Process. *Complexity*, 5(3): 26-33.

Brunk, Gregory G. 2001. Self-Organized Criticality: A New Theory of Political Behaviour and Some of its Implications. *British Journal of Political Science*, 31: 427-445.

Brunk, Gregory G. 2002(a). Why Are So Many Important Events Unpredictable? Self-Organized Criticality as the 'Engine of History'. *Japanese Journal of Political Science*, 3(1): 25-44.

Brunk, Gregory G. 2002(b). Why Do Societies Collapse? A Theory Based on Self-Organized Criticality. *Journal of Theoretical Politics*, 14(2):195-230.

Buchanan, Mark. 2001. *Ubiquity: The Science of History --- or Why the World is Simpler Than We Think*. London: Phoenix.

Carpenter, Stephen R. and Lance H. Gunderson. 2001. Coping With Collapse: Ecological and Social Dynamics in Ecosystem Management. *BioScience*, 51(6): 451-457.

Casti, John L. 1995. *Complexification: Explaining a Paradoxical World Through the Science of Surprise*. New York: Harper Perennial.

Casti, John, and Ralph Dum. 2002. *Brainstorming Meeting on Complex Systems*. European Commission and "Exystence" (*sic*), Brussels, April 2002.

Chase-Dunn, Christopher. 2001. World-Systems Theorizing", in: Jonathan Turner (Ed.) *Handbook of Sociological Theory*. New York: Plenum.

Chase-Dunn, Christopher, and Peter Grimes. 1995. World-Systems Analysis. *Annual Review of Sociology*, 21: 387-417.

Chase-Dunn, Christopher, and Thomas D. Hall. 1997. *Rise and Demise: Comparing World-Systems*. Boulder: Westview.

Chase-Dunn, Christopher, Alexis Alvarez, and Dan Pasciuti. 2002. *World-systems in the Biogeosphere: Three Thousand Years of Urbanization, Empire Formation and Climate Change*. IROWS Working Paper No. 11, Institute for Research on World-Systems, University of California, Riverside. [on-line]

Clark, W.C. and R.E. Munn. (Eds.) 1986. *Sustainable Development of the Biosphere*. Laxenburg, Austria: International Institute for Applied Systems Analysis, and London: Cambridge University Press.

Chu, Dominique, Roger Strand and Ragnar Fjelland. 2003. Theories of Complexity: Common Denominators of Complex Systems. *Complexity*, 8(3):19-30.

Connell, David J. 2002/2003. Multiple Constructions of the Environmental Crisis: A Sociocybernetic View. *Journal of Sociocybernetics*, 3(2): 1-12.

Crumley, Carol L. 2003(a). *Historical Ecology: New Paths Towards Collaboration*. Paper presented to a conference in Uppsala, Sweden, August 2003.

Crumley, Carol L. 2003(b). *Historical Ecology: Integrated Thinking at Multiple Temporal a*nd *Spatial Scales*. Paper presented to a conference on World-System History and Global Environmental Change, Lund University, Sweden. September 18-22, 2003.

Dearing, John A. 2003. *Integration of World and Earth Systems: Heritage and Foresight*. Paper presented to a conference on World System History and Global Environmental Change, University of Lund, Sweden, September 18-22, 2003.

Dempster, Beth. 2001. *Being Organizationally Ajar: An Alternative Heuristic for Understanding Change in System Organization*. Presentation to the American Society for Cybernetics, Vancouver, May 2001.

Devezas, Tessaleno, and George Modelski. 2003. Power Law Behavior and World System Evolution: A Millennial Learning Process. *Technological Forecasting and Social Change*, 70 (9): 819-859.

Elmquist, Thomas, Carl Folke, Magnus Nystrom, Garry Peterson, Jan Bengtsson, Brian Walker, and Jon Norberg. 2003. Response diversity, ecosystem change, and resilience. *Frontiers in Ecology and Environment*, 9:488-494.

Folke, Carl and 24 other authors. 2002. *Resilience and Sustainable Development: Building Adaptive Capacity in a World of Transformation*. Scientific Background Paper on Resilience for the Process of the World Summit on Sustainable Development on behalf of The Environmental Advisory Council to the Swedish Government.

Folke, Carl, Steve Carpenter, Brian Walker, Marten Scheffer, Thomas Elmquist, Lance Gunderson, and C.S. Holling. 2004. Regime Shifts, Resilience, and Biodiversity in Ecosystem Management. *Annual Review of Ecology and Evolutionary Systems*, 35:557-581.

Francis, George. 2004. *"Models" for Sustainability Emerge in an Open Systems Context*. Paper presented to the Georgia Basin Futures Project Conference on Interactive Sustainability. Vancouver, May 2004.

Fuchs, Christian. 2002(a). *Modern Society – A Complex, Evolutionary, Self-Organizing, Antagonistic System*. INTAS Project "Human Strategies in Complexity" Research Paper [www.self-organization.org]

Fuchs, Christian. 2002(b). *Concepts of Social Self-Organization*. HSIC Paper No. 4. [on-line]

Fuchs 2003. Structuration Theory and Self-Organization. *Systematic Practice and Action Research*, 16(2): 133-167.

Funtowicz, S.O. and J. Ravetz. 1993. Science for a Post-Normal Age. *Futures*, 25: 735-755.

Funtowicz, S. and J. Ravetz. 2003. Post-Normal Science. *Internet Encyclopedia of Ecological Economics*. International Society for Ecological Economics.

Geyer, Felix, and Johannes van der Zouwen. 1991. Cybernetics and Social Science: Theories and Research in Sociocybernetics. *Kybernetes*, 20(6): 81-92.

Geyer, Felix. 1994. *The Challenge of Sociocybernetics*. Paper for the 13th World Congress of Sociology, Bielefeld, July 1994.

Gunderson, L.H., C.S. Holling, and S.S. Light (Eds.) 1995. *Barriers and Bridges to the Renewal of Ecosystems and Institutions*. New York: Columbia University Press,

Gunderson, Lance. H. and C.S. Holling (Eds.) 2002. *Panarchy: Understanding Transformations in Human and Natural Systems*. Washington D.C: Island Press.

Heylighen, Francis. n.d. c2000. *Foundations and Methodology for an Evolutionary World View: a review of the Principia Cybernetica Project*. [on-line]

Hofkirchner, Wolfgang. 1998. Emergence and the Logic of Explanation: An Argument for the Unity of Science. *Acta Polytechnica Scandinavica, Mathematics, Computing and Management in Engineering Series*, 91;23-30.

Holling, C.S. (Ed.) 1978. *Adaptive Environmental Assessment and Management*. Laxenburg, Austria: International Institute for Applied Systems Analysis, and New York: John Wiley & Sons.

Holling, C.S. 1996. Surprise for Science, Resilience for Ecosystems, and Incentives for People. *Ecological Applications*, 6(3):733-735.

Holling, C.S. 2001. Understanding the Complexity of Economic, Ecological and Social Systems. *Ecosystems*, 4:390-405.

Hopkins, Terrence K. and Immanual Wallerstein. 1998. *The Age of Transition: Trajectory of the World System 1945-2025*. London: Zed Books.

Jessop, Bob. 2001. State theory, regulation, and autopoesis: debates and controversies. *Capital & Class*, No. 75: 83-92.

Jessop, Bob. 2002. *The Future of the Capitalist State*. Cambridge: Blackwell Publishing Polity Press.

Kauffman, Stuart. 2000. *Investigations*. New York: Oxford University Press.

Kay, James J., Henry A. Regier, Michelle Boyle and George Francis. 1999. An Ecosystem Approach for Sustainability: Addressing the Challenge of Complexity. *Futures*, 31:721-742.

Kay, James J., and Henry A. Regier. 2000. Uncertainty, Complexity, and Ecological Integrity: Insights from an Ecosystem Approach. Chapter 8 in: P. Crabbe, A. Holland, L. Ryszkowski and L. Westra. (Eds.) *Implementing Ecological Integrity: Restoring Regional and Global Environmental and Human Health*. NATO/Kluwer Academic Publishers.

Klauninger, Bert. 2002. *Causality and Emergence*. HSIC Paper No. 2. [on-line]

Kohler, Timothy A., George J Gumerman, and Robert G. Reynolds. 2005. Simulating Ancient Societies. *Scientific American*, 293(1): 76-84.

Lipietz, Alain, and Georges Benko. 1998. From the regulation of space to the space of regulation. *GeoJourna*l, 44(4): 275-281.

Luhmann, Niklas. 1995. *Social Systems*. Translated by John Bednarz. Stanford: Stanford University Press.

Manuel-Navarrete, David, James J. Kay, and Dan Dolderman. 2003. Different Ways of Framing the Discussion of Ecological Integrity. *Proceedings of the 3rd Biennial International Workshop on Advances in Energy Studies: Reconsidering the Importance of Energy*. Porto Venere, Italy. September 2002.

Midgley, Gerald. 2003. Science as Systemic Intervention: Some Implications of Systems Thinking and Complexity for the Philosophy of Science. *Systemic Practice and Action Research*, 16(2): 77-97.

Modelski, George. 1987. *Long Cycles in World Politics*. Seattle: University of Washington Press.

Modelski, George. 1996. Evolutionary Paradigm for Global Politics. *International Studies Quarterly*, 40: 321-342.

Modelski, George. 2003. *Ages of Redistribution*. Paper presented to the conference on World System History and Global Environmental Change, University of Lund, Sweden, 19-22 September 2003.

Moore, Jason W. 2003(a). Capitalism as World-Ecology: Braudel and Marx on Environmental History. *Organization & Environment*, 16(4): 431-458.

Moore, Jason W. 2003(b). The Modern World-System as Environmental History? Ecology and the rise of capitalism. *Theory and Society*, 32: 307-377.

Morris, Richard. 1999. *Artificial Worlds: Computers, Complexity, and the Riddle of Life*. New York: Plenum.

Murray, Tamsyn P., James J Kay, David Waltner-Toews and Ernesto Raez-Luna. 1999. *Adaptive Methodology for Ecosystem Sustainability and Health (AMESH): An Introduction.* Presentation to the Conservation Medicine Conference, White Oak Conservation Centre, Florida, May 1999.

Olsson, Per, Carl Folke, and Thomas Hahn. 2004. Socio-Ecological Transformation for Ecosystem Management: the Development of Adaptive Co-Management of a Wetland Landscape in Southern Sweden. *Ecology and Society*, 9(4):2 [on-line]

Peterson, Garry. 2000. Political ecology and ecological resilience: An integration of human and ecological dynamics. *Ecological Economics*, 35:323-336.

Peterson, G.D., T.D. Beard, B.E. Beisner, E.M. Bennett, S.G. Carpenter, G.S. Cumming, C.L. Dent, and T.D. Harlicek. 2003. Assessing future ecosystem services: a case study of the Northern Highlands Lake District, Wisconsin. *Conservation Ecology,* 7(3):1 [on-line]

Ravetz, J.R. 1999. What is Post-Normal Science? *Futures*, 31(7):647-653.

Ravetz, Jerry. 2004. The Post-Normal Science of Precaution. *Futures,* 36:347-357.

Redman, Charles L., and Ann P. Kinzig. 2003. Resilience of Past Landscapes: Resilience Theory, Society and the *Longue Durée*. *Conservation Ecology*, 7(1):14 [on-line]

Roe, Emery. 2001. Varieties of issue incompleteness and coordination: An example from ecosystem management. *Policy Sciences*, 34:111-133.

Roe, Emery, and Michel van Eeten. 2002. Reconciling Ecosystem Rehabilitation and Service Reliability Mandates in Large Technical Systems: Findings and Implications of Three Major US Ecosystem Management Initiatives for Managing Human-Dominated Aquatic-Terrestrial Ecosystems. *Ecosystems*, 5:509-528.

Rosser, J. Barkley. 2000. Aspects of Dialectics and Nonlinear Dynamics. *Cambridge Journal of Economics*, 24(3): 311-324.

Schneider, Eric D., and James J. Kay. 1995. Order from Disorder: The Thermodynamics of Complexity in Biology. pp. 161-172 in: Michael P. Murphy and Luke A.J.O'Neill (Eds.) *What is Life: The Next Fifty Years, Reflections on the Future of Biology*. Cambridge University Press.

Schneider, Steffen, n.d. *Post-Fordism, the Resurgence of the Local State, and New Forms of Urban Governance: Arguments and Deficits of an Emerging Meta-Narrative*. Augsberg: Institut fur Kanada-Studien.

Schoon, Michael. 2005. *A Short Historical Overview of the Concepts of Resilience, Vulnerability and Adaptation.* Indiana University. Workshop in Political Theory and Policy Analysis. Working Paper W05-4.

Tainter, J.A. 1988. *The Collapse of Complex Societies*. Cambridge: Cambridge University Press.

Tainter, J.A. 2000. Problem Solving: Complexity, History, Sustainability. *Population and Environment*, 22(1): 3-41.

Taylor, Philip. 2004. Resilience and Biosphere Reserves. *Environments*, 32(3):79-90.

Ulanowicz, Robert E. 1997. *Ecology, The Ascendent Perspective*. New York: Columbia University Press.

Ullsten, Ola, and David J. Rapport. 2001. On the Politics of the Environment: Ecosystem Health and the Political Process. *Ecosystem Health*, 7(1):2-6.

VanLeeuwen, J.A., D. Waltner-Toews, T. Abernathy and B. Smit. 1999. Evolving Models of Human Health Toward an Ecosystem Context. *Ecosystem Health*, 5(3):204-219.

Viskovatoff, Alex. 1999. Foundations of Niklas Luhmann's Theory of Social Systems. *Philosophy of the Social Sciences*, 29(4): 481-507.

Waldrop, M. Mitchell. 1992. *Complexity: The Emerging Science at the Edge of Order and Chaos*. New York: Touchstone.

Walker, B., S. Carpenter, J. Anderies, N. Abel, G. Cumming, M. Janssen, L. Lebel, J. Norberg, G.D. Peterson, and R. Pritchard. 2002. Resilience management in social-ecosystems:a working hypothesis for a participatory approach. *Conservation Ecology*, 6(1):14 [0n line]

Wallerstein, Immanual. 1991. *Geopolitics and Geoculture: Essays on the Changing World-System*. Cambridge: Cambridge University Press.

Wallerstein, Immanual. 1998. *Utopistics, or Historical Choices for the Twenty-First Century*. New York: W.W. Norton & Co., Inc.

Wallerstein, Immanual. 2003. *The Decline of American Power*. New York: W.W. Norton & Co., Inc.

Wallerstein, Immanual. 2005. *World-System Analysis: An Introduction*. 2nd printing. Durham: Duke University Press.

Waltner-Toews, David. 2003. *Ecosystem Sustainability and Health: A Practical Approach*. Presentation to the International Forum on Ecosystem Approaches to Human Health. International Development Research Centre, Montreal, May 2003.

Waltner-Toews, David. 2004. *Ecosystem Sustainability and Health: A Practical Approach*. Cambridge University Press.

Waltner-Toews, David, James J. Kay, Cynthia Neudoerffer, and Thomas Gitau. 2003. Perspective Changes Everything: Managing Ecosystems from the Inside Out. *Frontiers in Ecology and the Environment*, 1(1): 23-30.

Waltner-Toews, David [and James Kay]. 2004. The Evolution of the Ecosystem Approach: the Diamond Schematic and an Adaptive Methodology for Ecosystem Sustainability and Health. *Ecology and Society*, 10(1): 38. [on-line]

Weeks, Brian, Marko Antonio Rodriguez, and J.H. Blakeslee. 2004. *Panarchy: Complexity and Regime Change in Human Societies*. Proceedings: Santa Fe Institute Complex Systems Summer School.

Westra, L., Philippe Crabbe, Allan Holland, and L. Ryczkowski (Eds.) 2000. *Implementing Ecological Integrity: Restoring Regional and Global Envirnmental and Human Health*. Dordrecht, NL: Kluwer Academic Publishers.

Wilcox, Bruce A., A. Alonso Aguirre, Peter Daszak, Pierre Horwitz, Pim Martens, Margot Parkes, Jonathan A. Patz, David Waltner-Toews. 2004. EcoHealth: A Transdisciplinary Imperative for a Sustainable Future. *EcoHealth*, 1:3-5. [on-line]